CLAIMS

What is claimed is:

1. A method of making a magnetoresistive sensor formed with an electrically conductive spacer interposed between a first and a second ferromagnetic layer, comprising the steps of:

selecting a first material having a first electronegativity for said first ferromagnetic layer;

selecting a second material having a second electronegativity for said electrically conductive spacer; and

selecting a third material having a third electronegativity for said second ferromagnetic layer;

wherein an absolute value of a difference between said first and second electronegativities is minimized.

2. The method as in Claim 1, wherein said first and third electronegativities are approximately equal.

3. The method as in Claim 1, wherein said first material substantially comprises a superlattice.

4. The method as in Claim 3, wherein said second material substantially comprises a superlattice.

5. The method as in Claim 1, wherein said second material substantially comprises a superlattice.

6. The method as in Claim 1, wherein said first material and said second material comprise substantially the same crystal structure.

7. The method as in Claim 6, wherein said first material comprises a first face centered cubic material and said second material comprises a second face centered cubic material.

8. The method as in Claim 7 wherein said absolute value is less than approximately 0.12 eV.

9. The method as in Claim 7, wherein said step of selecting said second material includes the step of selecting said material from the group consisting of Cu, Ag, Al, Au, Ir, Pt, Pd, Rh, and binary, ternary and higher order alloys of said elements.

10. The method of Claim 7, wherein said step of selecting said second material includes the step of selecting said material from a group consisting of Ag_3Pt, $AgPt_3$, Cu_3Pt, $CuPt$, $CuPt_3$, Cu_3Pt_5, Cu_3Au, Cu_3Pd, $CuPd$, $CrIr_3$, Cr_2Pt and mixtures of said materials.

11. The method as in Claim 7, wherein said step of selecting said first material includes the step of selecting materials from the group comprising 80Ni:20Fe, Ni_3Fe, Ni_3Mn, Fe_4Mn, FePd, $Fe_{1-y}Au_y$, where y is an atomic fraction with a value between 0.30 and 0.70, $Co_{1-z}Au_z$, where z is an atomic fraction with a value between 0.10 and 0.50, 90Co:10Fe, $Fe_{0.485}Ni_{0.418}Mn_{0.097}$, $(48Co:29Ni:23Fe)_{(1-y)}Pd_y$, $(26Co:44Ni:30Fe)_{(1-y)}Pd_y$, where y is an atomic fraction of Pd with a value between 0.12 to 0.30, 33.6Co:20.3Ni:16.1Fe:30Pd, and 18.2Co:30.8Ni:21Fe:30Pd.

12. The method as in Claim 7, wherein said first material comprises a first body centered cubic material and said second material comprises a second body centered cubic material.

13. The method as in Claim 12 wherein said absolute value is less than approximately 0.07 eV.

14. The method as in Claim 12, wherein said step of selecting said second material includes the step of selecting said material from a group consisting of Cr, W, V, Nb, Mo, Ta and binary, ternary and higher order alloys of said elements.

15. The method as in Claim 12, wherein said step of selecting said first material includes the step of selecting ferromagnetic

materials from the group comprising $Fe_{1-u} Cr_u$, where u is an atomic fraction with a value between 0.40 and 0.70, $Fe_{1-w} V_w$, where w is an atomic fraction with a value between 0.25 and 0.35, ternary alloys of Fe, Cr and V, and Fe_3Al.

16. The method as in Claim 1, wherein said steps of selecting said first material and said second material each includes a step of defining said first and second electronegativities according to the following equations:

$$\chi\,(FM) = 0.44\,\phi\,(FM) - 0.15, \text{ and}$$

$$\chi\,(spacer) = 0.44\,\phi(spacer) - 0.15,$$

where $\chi(FM)$ and $\chi(spacer)$ are said first and second electronegativities, respectively, and $\phi(FM)$ and $\phi(spacer)$ are work functions of said ferromagnetic layer and said electrically conductive spacer, respectively.

17. The method as in Claim 16, wherein said step of selecting said second material includes the step of selecting a conductive alloy having an electronegativity χ_A formed of a plurality of elements 1 through i;

wherein said elements have electronegativities χ_1 through χ_i, and atomic fractions f_1 and f_i, respectively; and

wherein said χ_A is defined by the following equation:

$$\chi_A = \chi_1 f_1 + \chi_2 f_2 \ldots + \chi_i f_i \, .$$

18. The method as in Claim 16, wherein said step of selecting said first material includes the step of selecting a ferromagnetic alloy having an electronegativity χ_B and formed of a plurality of elements 1 through j;

wherein said elements have electronegativities χ_1 through χ_j, and atomic fractions f_1 and f_j, respectively; and

wherein said χ_B is defined by the following equation:

$$\chi_B = \chi_1 f_1 + \chi_2 f_2 \ldots \chi_j f_j$$

19. The method as in Claim 1, wherein said step of selecting said first material includes the step of selecting a first Heusler alloy.

20. The method as in Claim 19, wherein said first Heusler alloy has a composition of M_1MnM_2, where M_1 is an element selected from the group consisting of Al, Ga, Ge, As, In, Si, Sn and Bi, and M_2 is an element selected from the group consisting of Co, Ni, Cu, Ir, Pd, Pt and Au.

21. The method as in Claim 20, wherein said step of selecting said second material includes a step of selecting a second Heusler alloy that is nonferromagnetic and wherein M_2 is an element selected from the group consisting of Pt, Au, Pd and Ir, said second Heusler alloy having a bulk resistivity of less than approximately 30 $\mu\Omega$-cm.

22. The method as in Claim 20, wherein said step of selecting said second material includes a step of selecting a material from the group consisting of Cu, $Cu_{1-x}Au_x$, where x is an atomic fraction between .05 and .15, Al_2Au, $PtAl_2$ and $Ag_{1-y}Au_y$, where y is an atomic fraction less than .25.

23. The method as in Claim 1, wherein said first material comprises a material having a bulk resistivity of less than approximately 100 $\mu\Omega$-cm.

24. The method as in Claim ~~22~~ 20, wherein said third material comprises a material having a bulk resistivity of less than approximately 100 $\mu\Omega$-cm.

25. The method as in Claim 1, wherein said second material comprises a material having a bulk resistivity of less than approximately 30 $\mu\Omega$-cm.

26. A method of optimizing the interfacial properties of a magnetoresistive sensor comprising the steps of:

selecting at least one electrically conductive spacer having a first work function (ϕ spacer); and

selecting ferromagnetic layers having at least a second work function (ϕ FM);

wherein an absolute value of a difference between said first and second work functions is minimized.

27. A magnetoresistive sensor comprising:

first and second ferromagnetic layers, said first ferromagnetic layer comprising a first material having a first electronegativity; and

an electrically conducting spacer interposed between said ferromagnetic layers, and comprising a second material having a second electronegativity;

wherein an absolute value of a difference between said first and second electronegativities is minimized.

28. The sensor as in Claim 27, wherein said second ferromagnetic comprises a third material having a third electronegativity and said first and third electronegativities are approximately equal.

29. The sensor as in Claim 27, wherein said first material substantially comprises a superlattice.

30. The sensor as in Claim 29, wherein said second material substantially comprises a superlattice.

31. The sensor as in Claim 27, wherein said second material substantially comprises a superlattice.

32. The sensor as in Claim 27, wherein said first material and said second material comprise substantially the same crystal structure.

33. The sensor as in Claim 32, wherein said first material comprises a first face centered cubic material and said second material comprises a second face centered cubic material.

34. The sensor as in Claim 33, wherein said absolute value is less than approximately 0.12 eV.

35. The sensor as in Claim 33, wherein said second material is selected from the group comprising Cu, Ag, Al, Au, Ir, Pt, Pd, Rh, and binary, ternary and higher order alloys of said elements.

36. The sensor as in Claim 33, wherein said second material is selected from the group comprising Ag_3Pt, $AgPt_3$, Cu_3Pt, CuPt, $CuPt_3$, $\cancel{Cu_3Pt_5}$, Cu_3Au, Cu_3Pd, CuPd, $CrIr_3$, Cr_2Pt and mixtures of said materials.

37. The sensor as in Claim 33, wherein said first material is selected from the group comprising 80Ni:20Fe, Ni_3Fe, Ni_3Mn, Fe_4Mn, FePd, $Fe_{1-y}Au_y$, where y is an atomic fraction with a value between 0.30 and 0.70, $Co_{1-z}Au_z$, where z is an atomic fraction with a value between 0.10 and 0.50, 90Co:10Fe, $Fe_{0.485}Ni_{0.418}Mn_{0.097}$, $(48Co:29Ni:23Fe)_{(1-y)}Pd_y$, $(26Co:44Ni:30Fe)_{(1-y)}Pd_y$, where y is

an atomic fraction of Pd with a value between 0.12 to 0.30, 33.6Co:20.3Ni:16.1Fe:30Pd, and 18.2Co:30.8Ni:21Fe:30Pd.

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38. The sensor as in Claim 32, wherein said first material comprises a first body centered cubic material and said second material comprises a second body centered cubic material.

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39. The sensor as in Claim ~~36~~ 38, wherein said absolute value is less than approximately 0.07 eV.

40. The sensor as in Claim 38, wherein said second material is selected from a group consisting of Cr, W, V, Nb, Mo, Ta and binary ternary and higher order alloys of said elements.

41. The sensor as in Claim 38, wherein said first material is selected from the group comprising Fe_{1-u} Cr_u, where u is the atomic fraction with a value between 0.40 and 0.70, Fe_{1-w} V_w, where w is the atomic fraction with a value between 0.25 and 0.35, tenary alloys of Fe, Cr and V, and Fe_3Al.

42. The sensor as in Claim 27, wherein said first electronegativity corresponds to a first work function;

wherein said second electronegativity corresponds to a second work function; and

wherein said at least first and second work functions are matched for optimizing the interfacial properties of the data storage device.

43. The sensor as in Claim 27, wherein said first and second electronegativities are defined according to the following equations, respectively:

$$\chi\ (FM) = 0.44\ \phi\ (FM) - 0.15, \text{ and}$$

$$\chi\ (spacer) = 0.44\ \phi(spacer) - 0.15,$$

where $\chi(FM)$ and $\chi(spacer)$ are said first and second electronegativities, respectively, and $\phi(FM)$ and $\phi(spacer)$ are the work functions of said ferromagnetic layer, and said electrically conductive spacer, respectively.

44. The sensor as in Claim 43, wherein said second material comprises a conductive alloy having an electronegativity χ_A and formed of a plurality of elements 1 through i;

wherein said elements have electronegativities χ_1 through χ_i, and atomic fractions f_1 through f_i, respectively; and

wherein said χ_A is defined by the following equation:

$$\chi_A = \chi_1 f_1 + \chi_2 f_2 \ldots \chi_i f_i$$

45. The sensor as in Claim 43, wherein said first material comprises ferromagnetic alloy having an electronegativity χ_B and formed of a plurality of elements 1 through j;

wherein said elements have electronegativities χ_1 through χ_j, and atomic fractions f_1 and f_j, respectively; and

wherein said χ_B is defined by the following equation:

$$\chi_B = \chi_1 f_1 + \chi_2 f_2 \ldots \chi_j f_j$$

46. The sensor as in Claim 27, wherein said first material comprises a material having a bulk resistivity of less than approximately 100 $\mu\Omega$-cm.

47. The sensor as in Claim ~~46~~ 38, wherein said third material comprises a material having a bulk resistivity of less than approximately 100 $\mu\Omega$-cm.

48. The sensor as in Claim ~~27~~ 30, wherein said second material comprises a material having a bulk resistivity of less than approximately 30 $\mu\Omega$-cm.

49. The sensor as in Claim 27, wherein said first material is a first Heusler alloy.

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50. The sensor as in Claim 49, wherein said first Heusler alloy has a composition of M_1MnM_2, where M_1 is an element selected from the group consisting of Al, Ga, Ge, As, In, Si, Sn and Bi, and M_2 is an element selected from the group consisting of Co, Ni, Cu, Ir, Pd, Pt and Au.

51. The sensor as in Claim 50, wherein said second material comprises a second Heusler alloy that is nonferromagnetic and wherein M_2 is an element selected from the group consisting of Pt, Au, Pd and Ir, said second Heusler alloy having a bulk resistivity of less than approximately 30 $\mu\Omega$-cm.

52. The sensor as in Claim 27, wherein said second material comprises a material from the group consisting of Cu, $Cu_{1-x}Au_x$, where x is an atomic fraction between .05 and .15, Al_2Au, $PtAl_2$ and $Ag_{1-y}Au_y$, where y is an atomic fraction less than .25.

53. A method of optimizing the interfacial properties of a magnetoresistive sensor comprising the steps of:

selecting a substrate having a predetermined crystallographic orientation;

selecting ferromagnetic layers, each having a crystallographic orientation similar to said substrate crystallographic structure and having a first electronegativity; and

selecting at least one electrically conductive spacer having a crystallographic orientation similar to said ferromagnetic crystallographic structure and having a second electronegativity;

wherein an absolute value of a difference between said first and second electronegativities is minimized.

54. The method as in Claim 53, wherein, each of said selecting steps includes selecting a single crystal material for said substrate, said ferromagnetic layers and said electrically conductive spacer.

55. The method as in Claim 53, wherein said step of selecting said substrate includes selecting a substrate material with a face centered cubic structure;

wherein said step of selecting said ferromagnetic layers includes selecting a ferromagnetic layer material with a face centered cubic structure; and

wherein said step of selecting said conductive spacer includes selecting a spacer material with a face centered cubic structure.

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56. The method as in Claim 55, wherein said absolute value is less than approximately 0.14 eV.

57. The method as in Claim 53, wherein said step of selecting said substrate includes selecting a substrate material with a body centered cubic structure;

wherein said step of selecting said ferromagnetic layers includes selecting a ferromagnetic layer material with a body centered cubic structure; and

wherein said step of selecting said conductive spacer includes selecting a spacer material with a body centered cubic structure.

58. A method of optimizing the interfacial properties of a magnetoresistive sensor comprising the steps of:

selecting a substrate having a random crystallographic orientation;

selecting ferromagnetic layers, each having a random crystallographic orientation and having a first electronegativity; and

selecting an electrically conductive spacer having a random crystallographic orientation and having a second electronegativity;

wherein said selecting steps provide for minimizing an absolute value of a difference between said first electronegativity and said second electronegativity.

59. The method as in Claim 58, wherein said step of selecting said substrate includes selecting a substrate material with a face centered cubic structure;

wherein said step of selecting said ferromagnetic layers includes selecting a ferromagnetic layer material with a face centered cubic structure; and

wherein said step of selecting said conductive spacer includes selecting a spacer material with a face centered cubic structure.

60. The method as in Claim 59, wherein said absolute value is less than approximately 0.12 eV.

61. The method as in Claim 59, wherein said step of selecting said substrate includes selecting a substrate material with a body centered cubic structure;

wherein said step of selecting said ferromagnetic layers includes selecting a ferromagnetic layer material with a body centered cubic structure; and

wherein said step of selecting said conductive spacer includes selecting a spacer material with a body centered cubic structure.

62. The method as in Claim 61, wherein said absolute value is less than approximately 0.07 eV.

63. A method of optimizing the interfacial properties of a magnetoresistive sensor comprising the steps of:

selecting a substrate having a predetermined crystallographic orientation;

selecting ferromagnetic layers, each having a crystallographic orientation substantially similar to said substrate crystallographic orientation and having a first work function; and

selecting at least one electrically conductive spacer having a crystallographic orientation similar to said substrate crystallographic orientation and having a second work function;

wherein said selecting steps include the step of substantially minimizing a difference between said first and second work functions.

64. A method of optimizing the interfacial properties of a magnetoresistive sensor comprising the steps of:

selecting a substrate having a random crystallographic orientation;

selecting ferromagnetic layers, each having a random crystallographic orientation and having a first work function; and

selecting an electrically conductive spacer having a random crystallographic orientation and having a second work function;

wherein said selecting steps include minimizing a difference between said first and second work functions.

65. A magnetoresistive sensor comprising:

a substrate having a predetermined crystallographic orientation;

ferromagnetic layers, each having a crystallographic orientation similar to said substrate crystallographic orientation and having a first electronegativity; and

at least one electrically conductive spacer interposed between said ferromagnetic layers and having a crystallographic orientation similar to said substrate crystallographic orientation and having a second electronegativity;

wherein an absolute difference between said first and second electronegativities is minimized for optimizing the interfacial properties of the sensor.

66. The sensor as in Claim 65, wherein said ferromagnetic layers comprise single crystal structures and said electrically conductive spacer comprises a single crystal.

67. The sensor as in Claim 65, wherein said substrate comprises a material having a face centered cubic structure;

wherein said ferromagnetic layers comprise materials having face centered cubic structures; and

wherein said conductive spacer comprises a material having a face centered cubic structure.

68. The sensor as in Claim 67, wherein said absolute value is less than approximately 0.14 eV.

69. The sensor as in Claim 65, wherein said substrate comprises a material having a body centered cubic structure;

wherein said ferromagnetic layers comprise materials having body centered cubic structures; and

wherein said conductive spacer comprises material having a body centered cubic structure.

70. A magnetoresistive sensor comprising:

a substrate having a random crystallographic orientation;

ferromagnetic layers, each having a random crystallographic orientation and having a first electronegativity; and

an electrically conductive spacer interposed between said ferromagnetic layers and having a random crystallographic orientation and having a second electronegativity;

wherein an absolute difference between said first and second electronegativities is minimized for optimizing the interfacial properties of the sensor.

71. The sensor as in Claim 70, wherein said substrate comprises a material having a face centered cubic structure;

wherein said ferromagnetic layers comprise materials having face centered cubic structures; and

wherein said conductive spacer comprises a material having a face centered cubic structure.

72. The sensor as in Claim 71, wherein said absolute value is less than approximately 0.12 eV.

73. The sensor as in Claim 70, wherein said substrate comprises a material having a body centered cubic structure;

wherein said ferromagnetic layers comprise materials having a body centered cubic structure; and

wherein said conductive spacer comprises material having a body centered cubic structure.

74. The sensor as in Claim 73, wherein said absolute value is less than approximately 0.07 eV.

75. The magnetoresistive sensor as in Claim 70, wherein said ferromagnetic layers each comprise crystals having three faces: 111, 110 and 100, having individual electronegativities χ_{111}, χ_{100}, and χ_{110}, respectively; and

wherein said first electronegativity is defined by the following equation:

$$\chi(\text{average}) = 1/3\ (\chi_{111} + \chi_{100} + \chi_{110}).$$

76. The sensor as in Claim 70, wherein said electrically conductive spacer comprises crystals having three faces: 111, 110 and 100, having individual electronegativities χ_{111}, χ_{100}, and χ_{110}, respectively; and

wherein said second electronegativity is defined by the following equation:

$$\chi(\text{average}) = 1/3\ (\chi_{111} + \chi_{100} + \chi_{110}).$$

77. The sensor as in Claim 27, further comprising:

a substrate in atomic contact with a side of one of said ferromagnetic layers opposite said spacer; and

an antiferromagnetic layer in atomic contact with a side of another one of said ferromagnetic layers opposite said spacer;

wherein the sensor is a spin valve sensor.

78. The sensor as in Claim 77 further comprising a buffer layer interposed between one of said ferromagnetic layers and said substrate.

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79. The sensor in Claim 78, wherein said buffer layer is an element selected from a group consisting of Ta, Cr, Fe, Pt, Pd, Ir and Au.

80. The sensor as in Claim 27, further comprising:

a substrate in atomic contact with a side of one of said ferromagnetic layers opposite said spacer;

wherein the sensor is a giant magnetoresistive sensor, and said first and second ferromagnetic layers comprise a plurality of said first and second ferromagnetic layers and said electrically conductive spacer comprises a plurality of said spacers.

81. The sensor as in Claim 80 further comprising a buffer layer interposed between one of said ferromagnetic layers and said substrate.

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82. The sensor as in Claim 81, wherein said buffer layer is an element selected from a group consisting of Ta, Cr, Fe, Pt, Pd, Ir and Au.

83. A magnetoresistive sensor comprising in combination:

a substrate;

ferromagnetic layer means formed over said substrate and having a first electronegativity; and

electrically conductive spacer means formed on said ferromagnetic layer and having a second electronegativity;

wherein a magnetoresistive response characteristic ($\Delta R/R$) of the sensor is optimized by correlating said first and second electronegativities to $\Delta R/R$ by the following equation:

$$\Delta R/R \cong A - B\ |\Delta\chi|^{1/2},$$

where A and B are constant values and $|\Delta\chi|$ is an absolute value of the difference between said first and second electronegativities.

84. The sensor as in Claim 83, wherein said ferromagnetic layer means constitutes a plurality of ferromagnetic layers; and said conductive spacer means comprises a number of spacer layers interposed between said ferromagnetic layers; and

wherein said absolute value is minimized.

85. The sensor as in Claim 84, wherein said substrate comprises a material having a face centered cubic structure;

wherein said ferromagnetic layers comprise materials having face centered cubic structures; and

wherein said conductive spacer comprises a material having a face centered cubic structure.

86. The sensor as in Claim 85, wherein said absolute value is less than 0.12 eV.

87. A method of optimizing the magnetoresistive response ($\Delta R/R$) of a magnetoresistive sensor, comprising the steps of:

selecting ferromagnetic layers having at least a first electronegativity;

selecting at least one electrically conductive spacer having at least a second electronegativity; and

wherein said selecting steps include correlating said first and second electronegativities for optimizing $\Delta R/R$ in accordance with the following equation:

$$\Delta R/R \cong A - B\,|\Delta\chi|^{1/2},$$

where A and B are constant values and $|\Delta\chi|$ is an absolute value of the difference between said first and second electronegativities.

88. The method according to Claim 87, wherein said step of correlating includes the step of optimizing $\Delta R/R$ in view of the following relationship:

$$\Delta R/R \cong A - 2A\,|\Delta\chi|^{1/2}.$$

89. The method according to Claim 88, wherein the sensor includes a spin valve sensor, including the step of setting the constant value A equal to approximately 32.30.

90. The method according to Claim 88, wherein the sensor includes a giant magnetoresistive sensor having a first peak, including the step of setting the constant value A equal to approximately 245 for said first peak.

91. The method according to Claim 88, wherein the sensor includes a giant magnetoresistive sensor having first and second peaks, including the step of setting the constant value A equal to approximately 110 for said second peak.

92. The method according to Claim 88, wherein the sensor includes a giant magnetoresistive sensor having first, second and third peaks, including the step of setting the constant value A equal to approximately 45 for said third peak.

93. A magnetoresistive sensor comprising:

first and second ferromagnetic layers, wherein at least one of said layers comprise a superlattice material; and

an electrically conductive spacer interposed between said ferromagnetic layers.

94. The sensor of Claim 93, wherein said electrically conductive spacer comprises a superlattice material.

95. The sensor of Claim 93, wherein said first ferromagnetic layer has a first electronegativity, said electrically conductive spacer has a second electronegativity and an absolute value of a difference between said first and second electronegativities is minimized.

96. A magnetoresistive sensor comprising:
first and second ferromagnetic layers; and
an electrically conductive spacer interposed between said ferromagnetic layers, wherein said spacer comprises a superlattice material.

97. The sensor of Claim 96, wherein at least one of said ferromagnetic layers comprises a superlattice material.

98. The sensor of Claim 96, wherein said first ferromagnetic layer has a first electronegativity, said electrically conductive spacer has a second electronegativity and an absolute value of a difference between said first and second electronegativities is minimized.

99. A magnetoresistive sensor comprising:
a first and second ferromagnetic layer; and
an electrically conductive spacer interposed between said ferromagnetic layers;
wherein said first ferromagnetic layer comprises a first compound ferromagnetic layer having a first material with a first magnetostriction and a first thickness and a second ferromagnetic

material with a second magnetostriction and a second thickness; and

wherein a difference between a first product of said first thickness and said first magnetostriction and a second product of said second thickness and said second magnetostriction is minimized.

100. The sensor as in Claim 99, wherein a ratio between said first and second products is in a range of approximately .3 to approximately 3.

101. The sensor as in Claim 99, wherein said first and second materials have a first and second coercivity, respectfully, and an average of said first and second coercivities is minimized.

102. The sensor as in Claim 101, wherein said average is less than approximately ten oersteds.

103. The sensor as in Claim 99, wherein said first ferromagnetic material has a first electronegativity and is in atomic contact with said electrically conductive spacer, wherein said spacer has a second electronegativity and wherein an absolute value of a difference between said first and second electronegativities is minimized.

104. The sensor as in Claim 99, wherein said second ferromagnetic layer comprises a second compound ferromagnetic layer having a third ferromagnetic material and a fourth ferromagnetic material in atomic contact with said electrically conductive spacer, and wherein said first and fourth ferromagnetic materials comprise substantially the same composition and said second and third ferromagnetic materials comprise substantially the same composition.